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HYDRAULIC DESIGN OF PUMP STATION 5A CENTRAL AND SOUTHERN FLORIDA PROJECT

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IRRIGATION AND DRAINAGE
DIVISION

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HYDRAULIC DESIGN OF PUMP STATION 5A
CENTRAL AND SOUTHERN FLORIDA PROJECT

Edwin W. Eden, Jr.,[1] M. ASCE

SYNOPSIS

Pump station 5A is a unit of the Central and Southern Florida Project which, after construction, will provide water control for West Palm Beach Canal within the Lake Okeechobee agricultural area. The pump station will remove excess rainfall from the canal at the rate of 4,610 cubic feet a second with average static head of 9.2 feet. Determination of pump-station characteristics required for satisfactory water control within that area is presented together with results of studies to determine operating characteristics.

Immediately south of Lake Okeechobee in southern Florida, is an extremely productive area of over 1,000 square miles of organic soils. Originally, that area was a vast sawgrass "glade" or marsh, with marginal areas of "custard apple," maiden cane, and other water-loving plants. The continual growth and decay of those plants under semiwet conditions for many thousands of years has resulted in the accumulation of organic matter. Those deposits of organic matter have been developed for agricultural use. Principal crops grown are sugar cane, ramie and kenaf, (the fiber crops), and vegetables such as celery, string beans, sweet corn, and cabbage. Other extensive areas are developed for pastures.

The first serious effort to develop the area was made in the period 1912 to 1918, when four major canals were dug across the area from Lake Okeechobee to the Atlantic Ocean. The locations of those canals, which were dug to provide gravity drainage, are shown on plate 1. Although some early success was experienced in the drought years which followed, the canals did not afford adequate drainage because of the lack of slope and the length of canal required to provide gravity discharge into the ocean. However, the drainage effected clearly indicated a definite need for water control in addition to drainage. Complete water control would consist of: (1) Draining off excess rainfall before material damage could occur; (2) supplying supplemental water to permit maximum production during subnormal rainfall periods; and (3) controlling ground-water elevations to minimize the oxidation and subsequent subsidence of the pure organic soils without reducing production.

After the 1947 flood, which inundated large portions of the area for long periods of time, it became apparent that development of the entire area was beyond the financial ability of the individual landowners. In 1948, the Congress, acting on the appeal of local interests, authorized construction of the First Phase of the Central and Southern Florida Project. Pump station 5A is one of the major units of that project. It was proposed to serve that portion of the drainage area of West Palm Beach Canal which passes through the Lake Okeechobee agricultural area.

Area served.--Pump station 5A will serve a drainage area of about 230

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square miles adjacent to West Palm Beach Canal. As shown on plate 1, the area is bordered on the north by Lake Okeechobee; on the northeast by levee 8, which will intercept all drainage from slightly higher lands lying to the east and north; on the south by conservation area No. 1; and on the west by Hillsboro Canal drainage area. Since lands will be drained to the nearest canal for most economical and effective drainage, the divide between Hillsboro and West Palm Beach Canals will be roughly midway between the two canals--about parallel to the latter. At present, about 40 percent of the area is developed for agricultural use. The estimated acreage which is now devoted to the various crops is given in Table 1. Similar data for the estimated ultimate land use of the area are also given.

TABLE 1

Existing and ultimate land use
Watershed served by pump station 5A

Land use	Area (acres)	
	Present land use	Ultimate land use
Pasture for beef cattle	23,300	100,400
Sugar cane	17,000	18,000
Vegetable crops	12,000	11,000
Fiber crops	2,900	14,000
Rice	900	1,200
Field corn	None	2,600
Undeveloped	91,100	None
Total	147,200	147,200

The lands now developed are concentrated along the canal where a high degree of water control is possible with the existing improvements. The enlargement of West Palm Beach Canal and construction of pump station 5A will permit development of the entire area for productive use. However, the developing of the lands which are now idle will require clearing the land of native sawgrass and other vegetation, and construction of a drainage system which will consist of canals and pumps of adequate capacity to discharge all excess run-off from contiguous areas into West Palm Beach Canal. The facilities to be provided under the Central and Southern Florida Project will furnish the local landowners an outlet for excess water, while other construction will improve the water supply required for water control. Supplemental construction by local landowners is required for successful development of the area.

Pump capacity.--General.--The pump station will be required to remove excess water from the area before significant damage is caused. The required capacity varies with the growing season of the various crops, their state of maturity, and resistance to water damage. The growing seasons for the principal crops, together with estimated duration of flooding which would result in damage, are listed in Table 2. Another factor to be considered is the experience in the area which indicates that protection adequate to provide for the more intense rainfall is unwarranted, since such rains batter and cut the tender crops to a complete loss.

Existing capacities.--Early drainage of the agricultural area bordering the southerly shores of Lake Okeechobee depended largely on gravity systems. With the further development of the peat and muck lands, drainage districts

TABLE 2

Growing seasons of principal crops and maximum flooding before damage occurs

Crop	Growing season	Flood duration after which damage begins
Vegetables----------------	Sept. thru May	6 hours
Sugar cane----------------	Entire year	14 days
Fiber crops---------------	Entire year	13 hours
Pasture--(Pangola, Bahia, and Carib. grasses)-----	Entire year	4 days
St. Augustine grass------	Entire year	5 days
Para, Bermuda and carpet grasses-----------------	Entire year	1 month
Rice---------------------	Feb. thru Nov.	3 days
Field corn---------------	Feb. thru July	12 hours

were formed and pumping units were installed to improve the effectiveness of the drainage system. Many farmers installed private pumps to increase the effectiveness of water control. The discharge capacity of most of the larger pumping plants is equivalent to about 1-inch depth in 24 hours over the area served. A few have capacities of 1.5 inches. In addition to the large plants, there are a number of smaller plants which drain areas of 80 to 640 acres. Many of those are located within drainage districts and provide additional facilities for controlling the water table on individual farms. Capacities of those smaller pumps usually range from about 1.5 to 6 inches in 24 hours. Table 3 gives the pump capacities and pertinent data for three of the larger drainage districts in the northern Everglades.

TABLE 3

Pump capacities of existing drainage districts

Drainage district	Drainage area (acres)	Pump capacity	
		(g.p.m.)	(inches/day)
South Florida Conservancy--	30,645	768,000	1.33
Pahokee------------------	15,100	300,000	1.06
Ritta--------------------	7,740	180,000	1.23
Total--------------------	53,485	1,248,000	-
Average------------------	-	-	1.24

Recommendations of Everglades Experiment Station.--The Everglades Experiment Station reports that it is the general opinion of growers in the northern Everglades that facilities to remove 2 or 3 inches of water in 24 hours should be available on truck farms. Such removal should be possible over an entire farm. Larger facilities to provide for run-off of more than 3 inches could not be justified when balancing the higher costs of installations against the value of the additional crops saved. Since such quick removal is not necessary for sugar cane or pasture, 1 inch in 24 hours is considered to be sufficient for these crops.

Discussion.--The capacity of pump station 5A can be determined from comparative economics, i. e., the value of losses prevented against the cost of constructing, maintaining, and operating the pump station. However, where landowners are responsible for removing excess water from their individual lands, the design of West Palm Beach Canal and pump station 5A need only be adequate to convey and discharge water as rapidly as such water is received. The capacity required at pump station 5A can be much less than that required by the individual landowners since diversity of crops and farming operations will reduce the average volume per unit of area delivered into the canal. The maximum discharge to pump station 5A will be further reduced by canal storage. Consideration of those factors has led to the adoption of a capacity at pump station 5A capable of removing 3/4 inch a day from the drainage area tributary thereto. Such removal will require a total installed capacity of 4,610 cubic feet a second. Local interests have concurred in the adoption of this capacity.

Tailwater.--General.--The pump station will discharge into the north portion of conservation area No. 1 near the entrance of levee 8 borrow canal. The general location and ground configuration of conservation area No. 1 are shown on plate 2. Typical photographs of growth in that area are shown on plates 3 and 4. Levee 40 and levee 7 are the east and west boundaries, respectively, of the area. In order to facilitate the movement of water from the pump station, the borrow canals for levees 40 and 7 are located within the conservation area. The discharge from the pump station will be distributed through the area by flowing through the borrow canals and through the conservation area. Schematic sections through the canal are also shown on plate 2.

Flow through vegetated areas.--Conservation area No. 1 is completely covered by a thick growth of semiaquatic grasses and sawgrass, with occasional small hammocks containing thickets and heavy scrub growth. Generally, the vegetation affords from 4 to 8 feet of heavy grass-type cover. Intermittent flooding and draining, caused by weather cycles, encourage the growth of such grasses under pre-project conditions. During periods of heavy precipitation, the canals were inadequate to drain the area, and the ponded run-off flowed or seeped away very slowly. The overland flow through the Everglades to those canals and smaller outlets was so restricted by the vegetative cover that flooding of the conservation area occurred frequently. Observers in the area report that storm run-off has often ponded to the same depth above the ground surface over areas of several hundred square miles, despite differences in average ground elevation and the slight southward slope. To estimate tailwater conditions that would exist below pump station 5A, it was necessary to establish a basis for computing flow away from the structures and through the vegetated areas. For simplicity in computing water-surface profiles, it was desirable that friction coefficients for flow through the vegetated areas be comparable to the roughness coefficient "n" in the Manning formula. A study was made to derive such coefficient for flow through the vegetated area between Tamiami Train (where a rating curve was available) and Shark River, on the Gulf Coast in the Everglades National Park. The roughness coefficient was derived by backwater computations in which the roughness coefficient was varied until the elevation of the computed water surface at Tamiami Trail was equal to the elevation obtained for the same discharge from the rating curve for the outlets at that point. Elevation 1 foot[2] near the head of Shark River was used as a starting point for water-surface-profile computations. A roughness coefficient comparable to Manning's "n"

2. All stages and elevations throughout this paper refer to mean sea level datum.

of about 1.3 was required to produce proper agreement with the rating curve for Tamiami Canal outlets. It is realized that flow through the heavy vegetation at low velocities tends to be laminar rather than turbulent. While the Manning formula is based on turbulent flow, the roughness coefficient determined by the above method reflects the overall loss or resistance factor. Average velocities were found to be less than 0.02 foot a second. Those velocities would indicate that the water infiltrates rather than flows through the vegetation. It was considered that the vegetation would be bent over at greater depths, thus permitting water to pass over it more freely. As the velocity increases, more and more of the vegetation would be forced down, and numerous channels would develop. To simplify computations, it was assumed that flow through the conservation area for depths up to 4 feet could be computed by the Manning formula with a coefficient of 1.3 as derived from the study discussed above. About 4-foot depth, it was considered that 60 percent of the vegetative cover would be forced down, reducing the coefficient to about 0.01 for the layer above the 4-foot depth.

Normal tailwaters.--The tailwater-rating curve for the pump station was based on computed water-surface profiles. The profiles were started at spillway 10, the outlet of conservation area No. 1, about 20 miles south of the pump station. During flood periods, discharge from the pump station would flow down levee 7 and levee 40 borrow canals on the west and east sides of conservation area No. 1, respectively, with the remainder flowing to the south through the vegetated portion of the conservation area. In order to develop the maximum efficiency of the borrow canal adjacent to levee 40, a mowed strip 1,000 feet wide was proposed along the upper portion of the canal in the reach where additional conveyance would be effective. In any event, the actual mowing of that strip would be deferred until experience had proven that it was needed. The water-surface profiles were computed using standard backwater-computation procedures, working upstream in incremental reaches not over 10,000 feet in length. The water-surface profiles were computed for starting elevations of 14.0, 17.0, and 18.1 feet, representing the average drought, normal, and maximum water-surface at spillway 10. Water-surface profiles and tailwater-rating curves derived therefrom are shown on plate 5. Under normal conditions, with pump station 5A, levee 8 borrow canal, and pump station 6 discharging at full capacity (4,610, 2,000, and 2,920 cubic feet a second, respectively), the tailwater elevation at pump station 5A would be 19.4 feet. It is expected that this condition will prevail about 40 percent of the time.

Abnormal tailwater.--The project area is exposed to frequent tropical hurricanes since it is located in the southern latitudes, close to the Atlantic Ocean on one side and the Gulf of Mexico on the other. The passage of hurricanes in the proximity of open bodies of water creates a superelevation of the water surface or wind tide. On Lake Okeechobee, such wind tides have raised the lake surface as much as 10 feet. While it is expected that the dense growth of vegetation now covering the conservation area would reduce the wind tide, there is no assurance that such growth will continue with the change of water levels in that area after the project is substantially completed. Also, extensive areas are devoured by fire during periods of prolonged droughts, even under existing conditions. Although designing the pumps to deliver the full capacity under such conditions could not be justified, it was considered that the design of the pump station should be based on the maximum probable wind tide. Empirical data collected for Lake Okeechobee modified to correct for the difference in location and planform were used to estimate the maximum

wind tide on the conservation area under design conditions. It was estimated that the normal water surface in conservation area No. 1 at pump station 5A (17 feet) would rise to about 26.25 feet, under the most severe hurricane considered possible. A hurricane whose average wind velocity would not exceed 75 to 80 miles an hour, with gusts up to 100 miles an hour, would raise the water surface to about 21.6 feet. If pump station 5A was in full operation (4,610 c.f.s.) and levee 8 borrow canal was discharging at design capacity (2,000 c.f.s.), it is estimated that the water surface would be raised to about 30 feet under design hurricane conditions.

Intake elevation--non-operative.--The average elevation of natural ground along West Palm Beach Canal is from 13.5 to 14.5 feet. For successful agricultural use the optimum water-surface elevation along the canal is about 1 foot below the average ground surface, or about 13.0 feet. The selection of that elevation was concurred in by local interests.

Intake elevation--operative.--The design of West Palm Beach Canal and pump station 5A is interdependent since both designs will be based on the intake elevation of pump station 5A. The canal cross section will vary directly with that elevation, as will the pump engine size and fuel consumption. The intake elevation was based on an economic analysis of a number of comparative designs to determine the most economical combination of pump station and canal size. All costs were placed on an annual basis to permit a valid comparison between canal excavation which is a first cost, and fuel consumption which is an annual expenditure. The studies revealed that an overall fall in West Palm Beach Canal from Lake Okeechobee to pump station 5A of 7 feet would be most economical. As the maximum water level in the canal which would afford satisfactory drainage was 15.3 feet at Lake Okeechobee, the most economical intake elevation at pump station 5A was 8.3 feet. West Palm Beach Canal was designed to deliver 3/4-inch run-off a day from the drainage area, or 4,610 cubic feet a second at that elevation. Pump station 5A would discharge the water as fast as West Palm Beach Canal would deliver it to the pump station.

Head on the station.--The critical combination of tailwater and intake elevations was determined for use in the design. The results are summarized in Table 4.

The design of the structure was made safe under the conditions expected during hurricanes.

Performance.--In order to determine the operational characteristics of the pump station, the discharge from West Palm Beach Canal drainage area was determined for the 12-year period, 1938 through 1949. The water-surface elevation of conservation area No. 1 was based on routing studies which considered the following elements: (1) Rainfall on the area; (2) evapo-transpiration and seepage losses from the area; (3) inflow from Hillsboro and West Palm Beach Canals through pump stations 6 and 5A, respectively; and (4) outflow through the conservation area outlet, spillway 10. Plate 6 shows the variation of the pool elevation during the period included in the study. The discharge from the 230 square miles of drainage area of West Palm Beach Canal was based on average daily rainfall less the estimated evaporation and transpiration. Evaporation and transpiration were assumed to be equal to the evaporation measured by the United States Weather Bureau Class A evaporation station at Belle Glade. That station is located on the northern portion of the drainage area. When excess rainfall exceeded pump capacity (3/4-inch a day), it was assumed to be ponded within the area until pump capacity was

available for its removal. Unsatisfied evapo-transpiration was accumulated during the non-irrigation months and satisfied by irrigation water during the first month of the growing season.

TABLE 4

Tailwater and intake elevations, pump station 5A

Conditions	Elevation (ft.)		Head (ft.)
	Intake pump station 5A	Tailwater cons. area No. 1	
Normal:			
Station non-operative-----	13.0	17.0	4.0
Station operative at full capacity-----------------	8.3	19.4	11.1
Hurricane conditions:			
Station non-operative:			
Moderate hurricane-------	13.0	21.6	8.6
Design hurricane---------	13.0	26.25	13.25
Station operative at full power:			
Moderate hurricane-------	10.0*	24.5	14.5
Design hurricane---------	11.0*	30.0	19.0

NOTES: *Estimated

(1) It was assumed that levee 8 borrow canal would discharge at design capacity (2,000 c.f.s.), when pump station 5A is operating at full capacity.

(2) Conservation area wind tide and waves have a duration of not over 6 hours.

(3) Moderate hurricane has sustained velocity (10-min. average) of 75 m.p.h. with maximum gusts up to 100 m.p.h.

(4) Wind tides generated in canals have been considered insignificant.

The normal heads are used in the design of the pumping units and engines.

During the irrigation months (December through April), if rainfall was inadequate, evapo-transpiration losses were satisfied by diversion of water from Lake Okeechobee. In addition, water was diverted from Lake Okeechobee through West Palm Beach Canal and pump station 5A when the lake stage exceeded the maximum regulation elevation and local run-off was less than 4,610 cubic feet a second. The intake water-surface elevation will be a function of the inflow to the station and the rate of discharge which varies with the pumping head and the number of pumps operating. Normally the water surface in West Palm Beach Canal would be controlled at elevation 13.0 feet to prevent overdrainage. The pump capacity will be used to prevent the water surface from rising above the optimum elevation in the canal insofar as possible. If the rate of pumping is greater than the inflow, the water surface at the pump station will drop to or below 8.3 feet. If the rate of pumping is less than the inflow, the water surface at the pump station will tend to rise. Under this condition, the water surface near the upper end of West Palm Beach Canal will also rise, depending on the available canal storage at that time.

Discharge duration.--The data from the routings indicate that pump station 5A will operate about 28.4 percent of the time or about 104 days a year. The flow-duration curve shown on plate 7 indicates that the pumping plant will

operate at maximum capacity (4,610 c.f.s.) about 5.4 percent of the time or about 20 days a year. The average annual volume of water pumped will be 430,000 acre-feet, of which about 60 percent will be excess rainfall from the agricultural area and the remainder of the water will be diverted from Lake Okeechobee.

Head duration.--The estimated intake and tailwater elevations were determined for each daily pumping period. The average head duration for the pump station was established by summation of the differential between the intake and tailwater elevations for each period weighted in direct proportion to the volume of water pumped. The head duration for the station is shown on plate 8. As shown, the average during the period was 9.2 feet, while the range in head was from a maximum of 11.1 feet to practically zero.

SUMMARY

The design of pump station 5A and anticipated performance are summarized in Table 5.

TABLE 5

Design and anticipated performance, pump station 5A

Station capacity	4,610 c.f.s.
Water-control elevation	13.0 ft.
Intake elevation	8.3 ft.
Tailwater:	
Minimum	10.0 ft.
Normal	19.4 ft.
Maximum	30.0 ft.
Pumping head	11.1 ft.
Average head	9.2 ft.
Average annual pumpage	430,000 acre-ft.

ACKNOWLEDGMENTS

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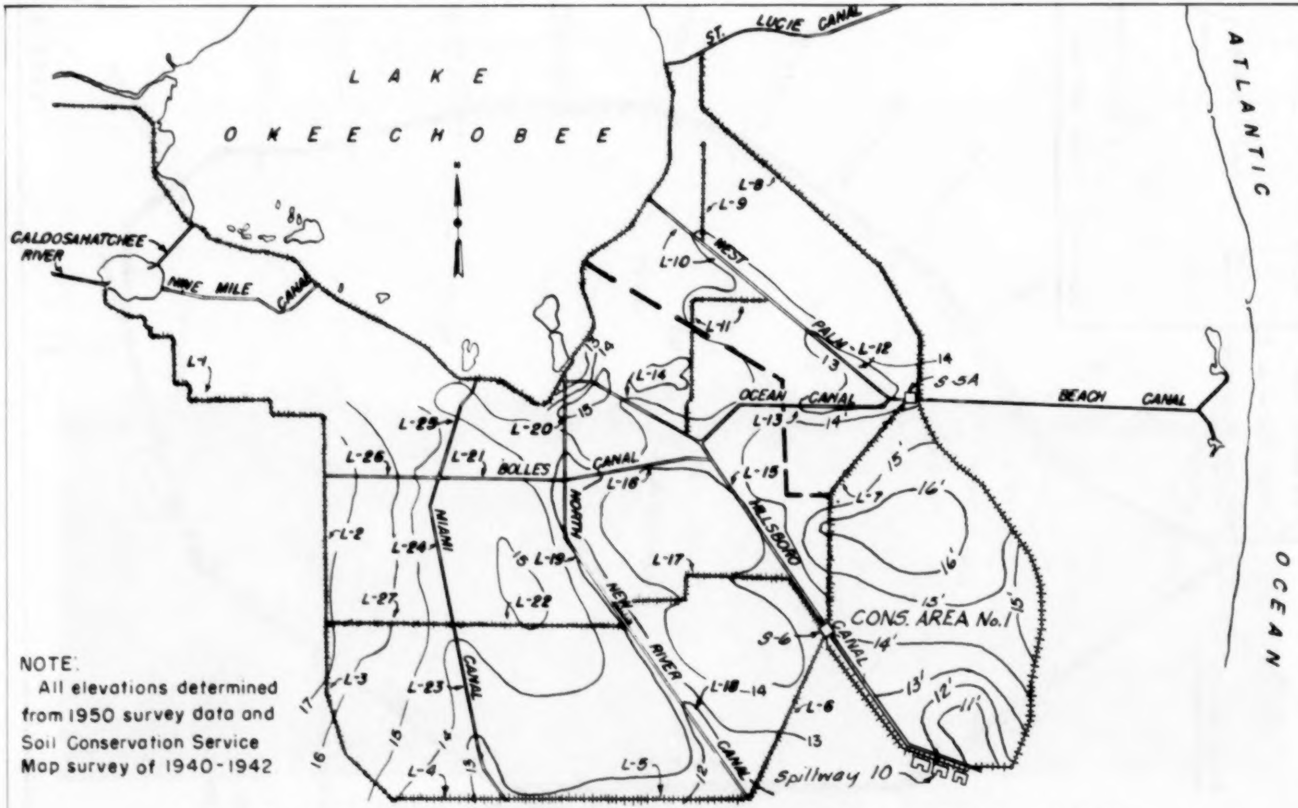
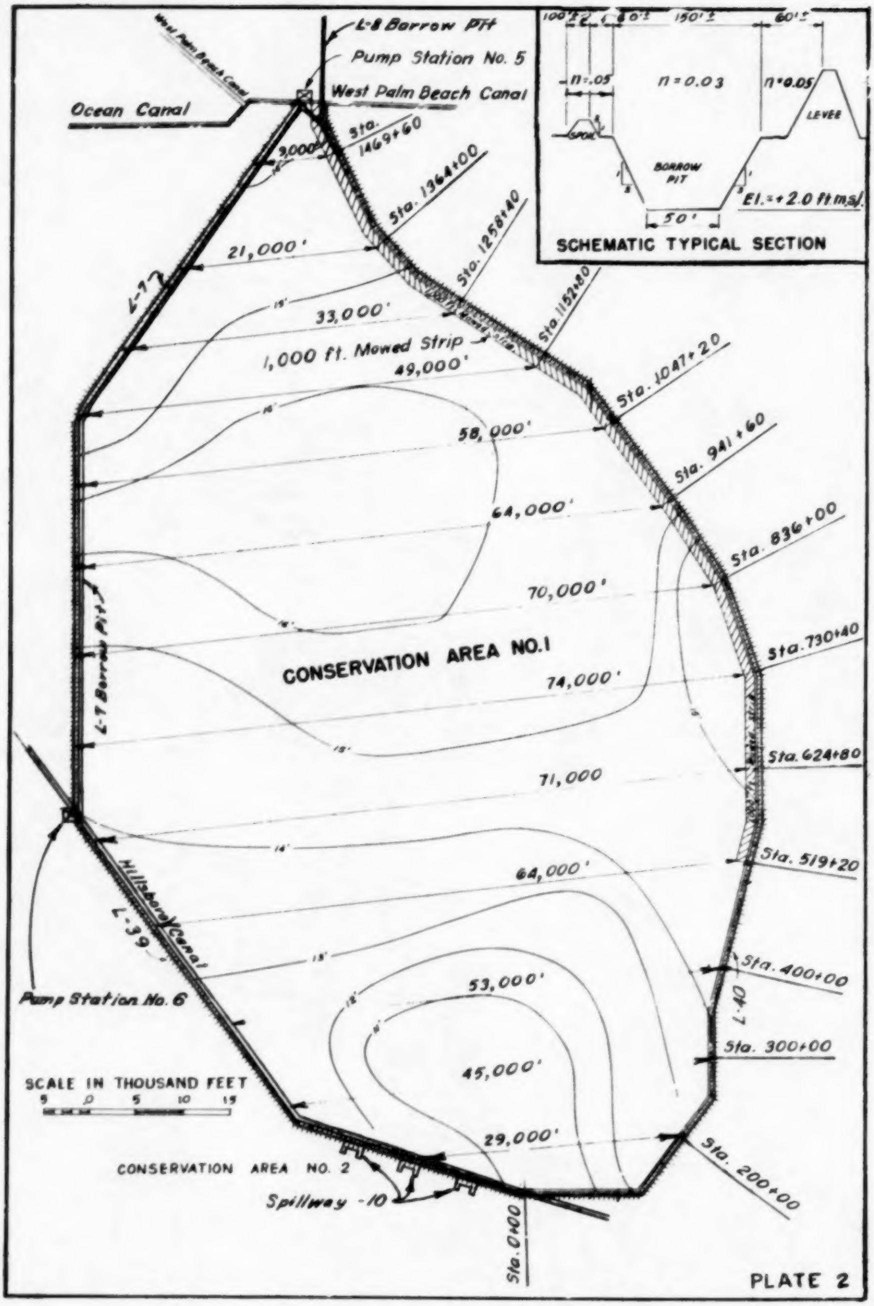


CONTOURS OF NATURAL GROUND SURFACE AGRICULTURAL AREA PLATE I


L-8 Borrow Pit
Pump Station No. 5
West Palm Beach Canal
Ocean Canal
Sta. 1469+60
Sta. 1364+00
Sta. 1258+40
Sta. 1152+80
Sta. 1047+20
Sta. 941+60
Sta. 836+00
Sta. 730+40
Sta. 624+80
Sta. 519+20
Sta. 400+00
Sta. 300+00
Sta. 200+00
Sta. 0+00
9,000'
21,000'
33,000'
1,000 ft. Mowed Strip
49,000'
58,000'
64,000'
70,000'
CONSERVATION AREA NO. 1
74,000'
71,000
64,000'
53,000'
45,000'
29,000'
L-7
L-7 Borrow Pit
L-39
Hillsboro Canal
L-40
Pump Station No. 6
SCALE IN THOUSAND FEET
5 0 5 10 15
CONSERVATION AREA NO. 2
Spillway -10
n=.05
n=0.03
n=0.05
LEVEE
BORROW PIT
El.=+2.0 ft msl.
50'
150'
60'
SCHEMATIC TYPICAL SECTION
PLATE 2

TYPICAL HEAVY VEGETATION

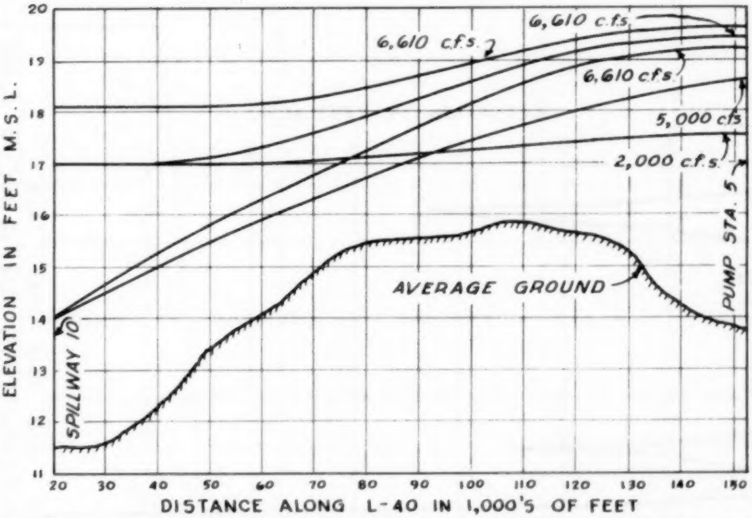
CONSERVATION AREA NO. I COVER

PLATE 3

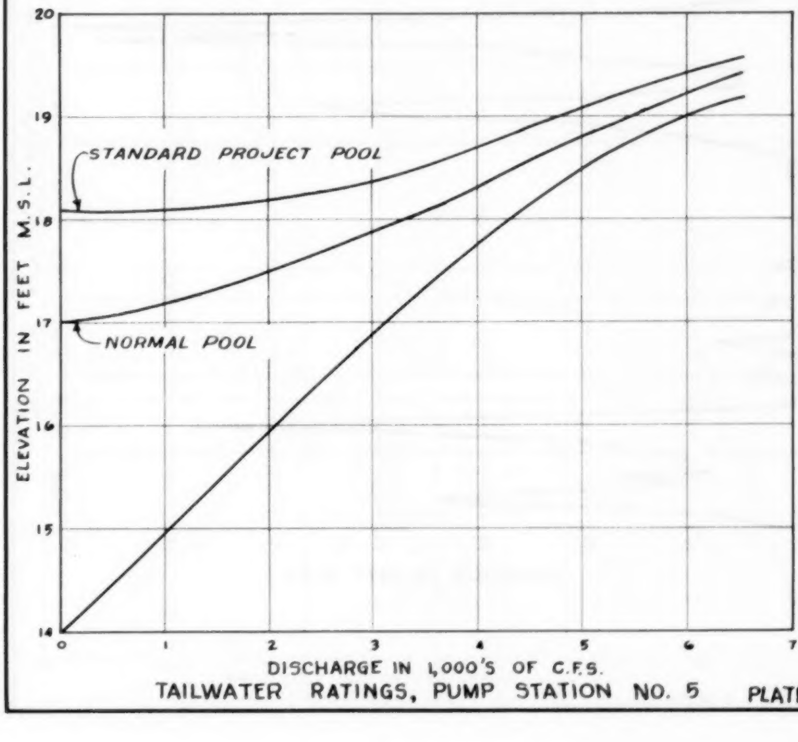
TYPICAL MARSH

CONSERVATION AREA NO. I COVER

PLATE 4

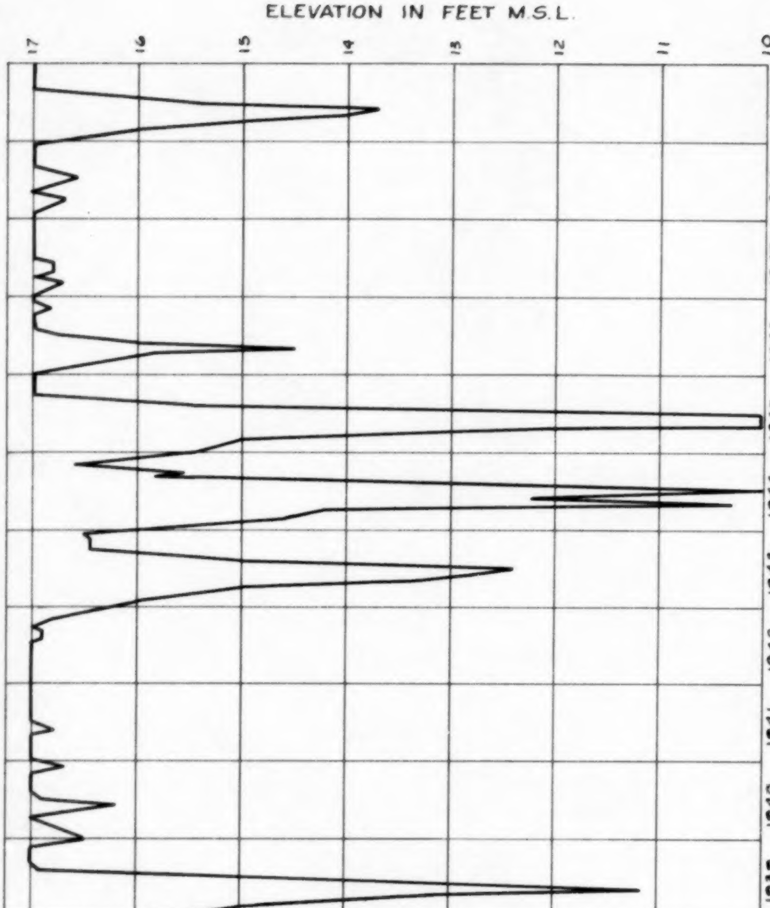


WATER-SURFACE PROFILES THROUGH CONSERVATION AREA NO. 1

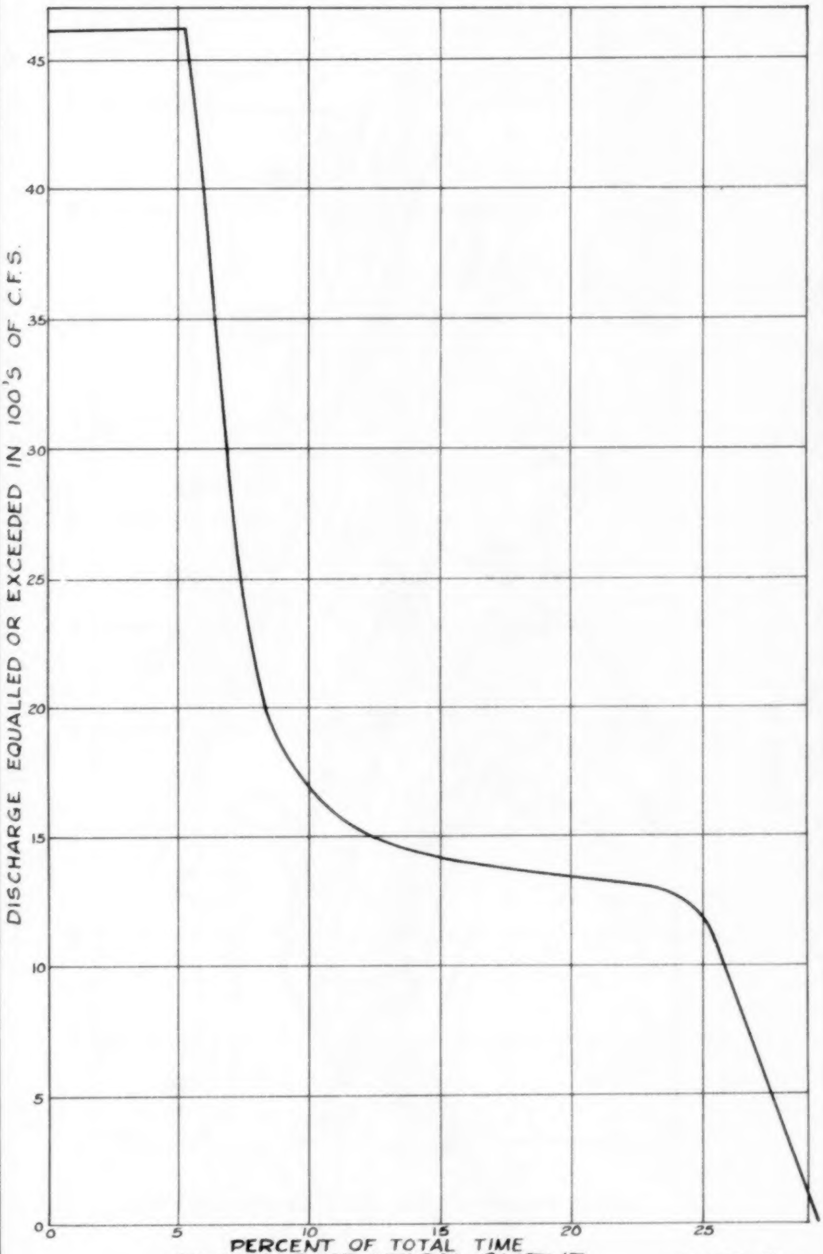


TAILWATER RATINGS, PUMP STATION NO. 5

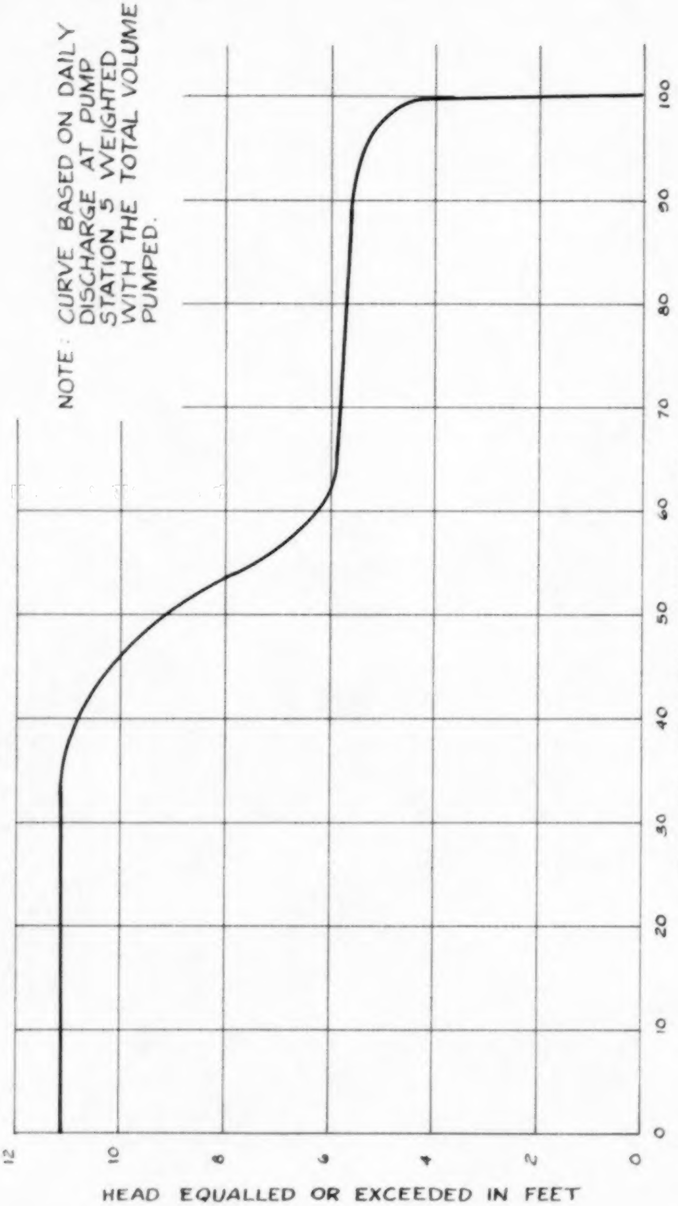
PLATE 5



STAGE HYDROGRAPH FOR CONSERVATION AREA NO. 1 PLATE 6

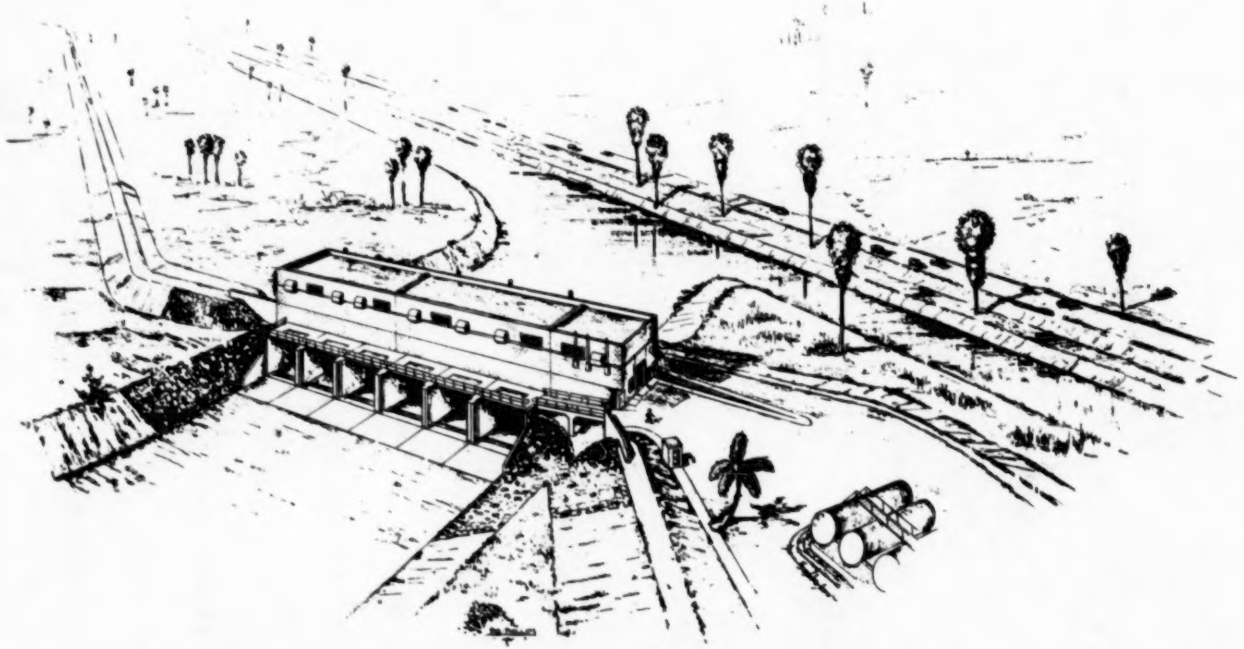


FLOW DURATION CURVE PLATE 7



HEAD DURATION, PUMP STATION NO. 5

PLATE 8



CORPS OF ENGINEERS, U.S. ARMY

PERSPECTIVE VIEW OF PUMP STATION 5A

PLATE 9